

Original Research Article

Irrigation with Controlled Water Stress and its Effects on Physiology and Phenology of 'Navelate' Oranges

ABSTRACT

Aims: The aim of this research was to study physiological responses and changes on phenology of 'Navelate' orange trees submitted to different intensities of water stress in greenhouse.

Study design: The experimental design was completely randomized, with three replications in each experimental unit. Values of each parameter was submitted to analysis of variance, compared by Tukey's test at 5% significance and showed as average.

Place and Duration of Study: The experiment was carried out in a greenhouse (latitude 31°52'00 "S, longitude 52°21'24" W, 13 m above sea level), during 2014 and 2015.

Methodology: Stressed conditions were based on 50% and 25% of the field capacity. Gas exchange [photosynthesis (A), transpiration (E), stomatal conductance (gs), internal CO₂ concentration (Ci), water use efficiency (WUE)] were analyzed using an infrared gas analyzer model Li-6400 (Portable Photosynthesis System LICOR, Nebraska, USA) in addition to growth parameters.

Results: It was observed reductions on photosynthetic rate (10.74% for T-50, and 20.66% for T-25, both compared to Control), indicating that CO₂ assimilation rate were affected by water stress conditions. Water stress affected all gas exchange parameters of the exposed orange trees, limiting growth in diameter and height. Fruit yield decreased with the amount of water (100% > 50% > 25%).

Conclusion: The submission of orange trees to amount of water lower than 50% of field capacity undertakes gas exchange, reducing plants growth and development and also fruit production.

Keywords: water stress; *Citrus spp.*; gas exchange; photosynthesis; fruit production.

1. INTRODUCTION

Orange is a fruit of great importance in Brazil, the country is the world's largest orange producer, producing 16,240,000 tons, other countries show high orange production, such as China which has the second largest production 7,823,550 tons, and India which holds the third largest production 7,313,610 tons [1]. Approximately 70% of orange production in Brazil belongs to São Paulo state, which produces about 11,628,150 tons and Rio Grande do Sul is the fifth largest producer, state orange production is 399,296 tons [2].

Water stress is one of the most frequent environmental factor which limits orange (*Citrus sinensis*) crop expansion in several places around the world. This water deficit can be resulted by an excessive soil water deficit or by an excessive water loss by transpiration in relation to water absorption by root system. In trees, a high evaporative demand of atmosphere promotes high transpiration rates, influencing water potential of leaves because of low hydraulic conductivity of root system [3].

Study of physiological parameters, such as photosynthetic rates, transpiration rates, and stomatal conductance are very important to evaluate drought tolerance in several plant species by elucidating changes on both production and quality of fruits. Citrus under several water stress close their stomata in order to reduce water loss through transpiration. Those plants can also limits CO₂ diffusion to substomatal cavity, resulting in reduction photosynthetic rate and increase of foliar temperature [4]. Southern Brazil, which is one of production areas of oranges, have subtropical climate with low temperatures during winter season and both warm and rainy during summer season [5]. Under these conditions, it seems to be necessary to study about citrus crop response to water stress, analyze how to choose a better water management during drought season and because of worldwide climate changes. Evaluation of gas exchange and water state of citrus plants can indicate the best conditions to keep both water and carbon balance during drought season in this region.

The objective of this work was to analyze physiological responses and phenology changes on 'Navelate' orange trees submitted to water stress conditions.

2. MATERIAL AND METHODS

The experiment was conducted in greenhouse of Fruit Crop Sector, Federal University of Pelotas, Brazil (Latitude 31°52'00" S; Longitude 52°21'24" W; altitude 13 m). The climate of this region is Cfa, according to Köppen-Geiser climate classification.

Evaluations were done between July 2014 and May 2015 in 'Navelate' orange trees. Young plants were obtained from commercial nurseries and cultivated in 26 L pots, and received same irrigation amount during acclimation period of 45 days. After this period, plants received distinct water management: control (substrate humidity corresponding 100% of field capacity), T-50 (substrate humidity corresponding 50% of field capacity), and T-25 (substrate humidity corresponding 25% of field capacity).

Gas exchange analyzes, growth measurement, and phenology evaluations were done after acclimation period, monthly during 210 days from August 2014 until March 2015.

Gas exchange analyzes were done according to following parameters: photosynthetic rate (A), transpiration rate (E), stomatal conductance (gs), and internal CO₂ concentration (Ci). Evaluations were done by using an infrared gas analyzer model Li-6400 (Portable Photosynthesis System LICOR, Nebraska, USA), with a photosynthetic active radiation intensity of 1200 μmol.m⁻².s⁻¹, measured in previously selected completely expanded leaves. The evaluations were recorded when the coefficient of variation (CV) was less than 0.5% and in temporal stability. Water use efficiency (WUE) and intrinsic water use efficiency (IWAUE) were calculated according to follow equations: $EUA (\mu\text{mol CO}_2 \text{ mmol}^{-1} \text{ H}_2\text{O}) = \text{Photosynthesis} / \text{Transpiration}$, and $IWUE (\mu\text{mol CO}_2 \text{ mmol}^{-1} \text{ H}_2\text{O}) = \text{Photosynthesis} / \text{Stomatal Conductance}$, respectively.

The experimental design was completely randomized, with three replications in each experimental unit. Values of each parameter was submitted to analysis of variance, compared by Tukey's test at 5% significance and showed as average.

3. RESULTS AND DISCUSSION

During this experiment, it was not observed changes on gas exchange and plant phenology until 100 days after started treatments of controlled water stress (Figure 1A). After this period, it was observed reduction in this parameter according to the treatments: T-25 < T-50 < Control.

Changes were also observed in water use efficiency (Figure 1C), leaf temperature (Figure 1D), and vapor pressure deficit (Figure 1F) in plants submitted to controlled water deficit in comparison to control plants.

Internal CO₂ concentrations, in general, followed gas exchange, showing values lower than the control. Capacity to maintain physiological activity throughout reduction of water availability result in some consequences, such as changes on gas exchange. In fact, it was observed changes on photosynthetic rate and reductions on stomatal conductance in plants submitted to higher deficit of atmospheric vapor pressure. This lower level of stomatal opening, which occurred in plants submitted to water stress, was a consequence of reduction of turgor pressure of cells, a higher deficit of atmospheric vapor pressure, or by chemical signals coming from root system [6,7].

Ramos and co-workers [8] observed that metabolism of orange plants were strongly affected by thermal regime, resulting in physiological changes related to photosynthesis, exportation of photoassimilates, and photosynthetic pigments, which changed both fruit development and composition. Therefore, exposition of orange plants to temperatures higher than optimal can result in reduction of both photosynthesis rate and carbohydrate metabolism. Reduction in CO₂ assimilation can be resulted as a consequence of closing the stomatal pores, and also because of possible photochemical damages in photosynthetic membranes [9]. Increase of air temperature, and

consequently increase of leaf temperature, promoted a reduction on photosynthetic rate because of increase on respiration rate [10,11].

Results obtained from this work corroborated with Pedroso and co-workers [12], which found substantial suppression on gas exchange in plants submitted to water stress. According to this author, water deficit resulted in proline accumulation in leaves, reduction on water potential, stomatal conductance, respiration rate, CO₂ assimilation, and mass accumulation. This reduction on photosynthetic activity caused by water stress occurred at same time of reduction on decrease of turgor pressure [13].

One of the first reaction of orange plants grown under severe stress can be to close the stomatal pores, in order to minimize water loss [14]. The tendency of reduction on transpiration rate observed in all treatments coincided with significant reduction on stomatal conductance throughout the experiment (Table 1). Direct correlation between transpiration and stomatal conductance were expected because of reduction on vapor flux to atmosphere caused by closing the stomatal pores.

Water management affected gas exchange in plants submitted to water stress. It was observed significant differences in photosynthetic rate, stomatal conductance, transpiration rate, and internal CO₂ concentrations (Table 1).

Under water stress conditions it was observed highest values of water use efficiency, probably because of reduction on stomatal conductance and consequently reduced the photosynthetic rate when compared to control (Table 1). Ma and co-workers [15] concluded that high photosynthetic rate associated with lower stomatal conductance and transpiration rate are typically observed in plants which tolerate lower water availability, but it was not clearly observed in this experiment.

It was observed reductions on photosynthetic rate (10.74% for T-50, and 20.66% for T-25, both compared to Control), indicating that CO₂ assimilation rate were affected by water stress conditions (Table 1). Internal CO₂ concentrations were higher in plants under water stress, probably because of closing the stomatal pore, resulting in both lower transpiration and respiration rates. The intrinsic water efficiency levels did not differ significantly between treated plants and control, but it was higher under water stress conditions. It could be related to lower levels of stomatal conductance. The correlation between CO₂ absorption and water consumption occurred when the stomatal pores are partially closed in the beginning of water stress condition. At this time, diffusion processes are promptly reduced, and the intrinsic water efficiency levels reaches the highest values. So, under severe water stress, dehydration of mesophyll cells strongly inhibits plant metabolism and photosynthesis [14].

Orange plants had morphological characteristics and physiological mechanisms which give considerably tolerance to water stress when compared to other perennial plants [16], but productivity are closely related to water availability. Since the photosynthetic rate are affected by water deficit, a reduction on both carbohydrate levels and fruit weight, which can affect fruit quality [17,18].

The organic matter accumulated in a plant came from photosynthesis, and represented 95% of its dry matter [19,20], and around 60% are in root system in orange seedlings [21]. In this experiment, the highest growth rate (height and trunk diameter) occurred in plants with appropriate water supply (Control), which had higher photosynthetic rate, when compared to plants grown under water stress (T-50 and T-25). With water restriction, both T-50 and T-25 plants showed reduction on trunk growth (diameter) and leaf expansion. These responses to acclimation limited water consumption by different tissues, helping to keep water status of those plants [6].

Following changes of trunk diameter and plant height, it was also observed reduction on fruit production. T-25 plants had reduction on both fruit size (-70%) and weight (-112%) compared do Control. Some authors concluded that reduction on productivity occurred when water stress occurred were applied during both flowering and fruit set stages [22, 23]. In our experiment, water deficit were applied since vegetative growth stage, but reduction on fruit production was observed in plants grown under water deficit conditions.

It was found no changes on plant growth rates and production in plants irrigated with both 25% and 100% of crop evapotranspiration [24]. However, those plants were irrigated with 100% of crop

evapotranspiration after 'june drop' phase until stage of rapid fruit growth. It can be concluded that a controlled water deficit can improve water use efficiency.

Table 1. Average values of photosynthetic rate (A), stomatal conductance (E), transpiration rate (gs), internal CO₂ concentration (Ci), and intrinsic water use efficiency (IWUE) in 'Navelate' oranges submitted to different levels of irrigation [substrate humidity corresponding 100% (Control), 50% (T-50), and 25% (T-25) of field capacity], evaluated monthly from August 2014 until March 2015.

	A	E	gs	Ci	IWUE
Trataments	($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)	($\text{mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)	($\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)		($\text{mmol}\cdot\text{mol}^{-1}$)
Control	6.05 ^a	3.06 ^a	0.06 ^a	206.88 ^c	1.98 ^{ns}
T-50	5.40 ^a	2.64 ^b	0.05 ^a	282.47 ^a	2.01 ^{ns}
T-25	4.80 ^{a*}	2.41 ^b	0.04 ^{a*}	231.78 ^b	1.99 ^{ns}

* Values followed by same letter did not differ at the 5% probability level by Tukey's test.

* Means by comparison in a column and indicates differences among treatments in different times.

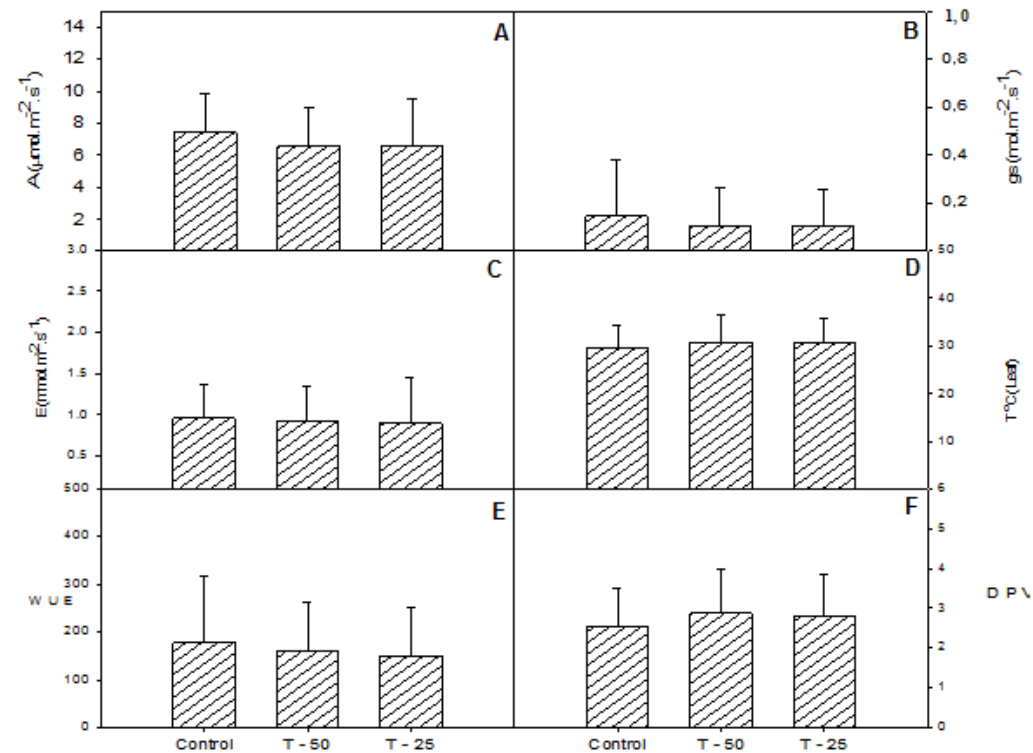


Fig. 1. Photosynthetic rate (A), stomatal conductance (B), transpiration rate (C), leaf temperature (D), water use efficiency (E), and vapor pressure deficit (F), in 'Navelate' oranges submitted to different levels of irrigation [substrate humidity corresponding 100% (Control), 50% (T-50), and 25% (T-25) of field capacity], evaluated monthly from August 2014 until March 2015.

Finally, a global climate change can be resulted in adverse conditions to plant growth. Moreover, under such conditions they should acclimate and adapt to survive. Resistance to water deficit in citrus plants, for example, is based on tolerance (osmotic adjustment) and prevention (stomatal control) to water stress, and the stomatal control is very developed in this genus [25, 26].

4. CONCLUSION

Orange plants submitted to 25% of irrigation of total field capacity showed reduction on stomatal conductance, transpiration and photosynthesis rate, which reduced plant growth (trunk diameter and plant height), both fruit production and quality. The best growth and production occurred in plants with any irrigation deficit. Deficient irrigation showed no changes in water use efficiency (normal and intrinsic), which means a good parameter of adaptation for stress condition. Water stress, in any level, reduced both plant growth and fruit production

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